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MEASUREMENT OF VHF SIGNAL ATTENUATION AND ANTENNA
IMPEDANCE DURING THE ASCENDING FLIGHT OF A SLENDER PROBE
AT VELOCITIES UP TO 17,800 FEET PER SECOND

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For Presentation at Second Symposium on
the Plasma Sheath

Boston, Massachusetts
April 10-12, 1962

(NASA-TM-X-69927) MEASUREMENT OF VHF
SIGNAL ATTENUATION AND ANTENNA IMPEDANCE
DURING THE ASCENDING FLIGHT OF A SLENDER
PROBE AT VELOCITIES UP TO 17,800 FEET
PER SECOND (NASA) 27 p

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ABSTRACT

The ascending flight of a slender probe flown from NASA, Wallops Station at velocities up to 17,800 ft/sec is described. The rocket model, payload, experiment, and flight trajectory are described and the VHF attenuation, VSWR, and antenna impedance measurement results are given. Predicted signal attenuations, according to the two limiting thermo-chemical-flow models, equilibrium and frozen-flow, are compared with the flight results, pointing up the need for a more detailed chemical kinetics approach.

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INTRODUCTION

This paper describes a radio attenuation measurements experiment launched from NASA Wallops Station on August 30, 1961. The purpose of the test was to conduct a carefully controlled experiment to evaluate our prediction capabilities of data transmission loss through plasma using available flow field and electromagnetic theories.

EXPERIMENT DESIGN

Primary considerations in the design of the experiment were as follows:

1. Control of vehicle attitude to provide small flow angles during data period.
 2. Run experiment close to launch area to insure continuous radar trajectory data and strong telemeter signals with a minimum of multipath interference.
 3. Ground range stations located so as to provide a wide range of look angles.
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4. No contamination of flow by ablation products from heat-protection materials.

5. A simple geometric shape to facilitate flow field predictions yet a shape that would provide some attenuation but not total blackout.

6. Antenna patterns to minimize signal strength variations resulting from small attitude changes.

VELOCITY-ALTITUDE TRAJECTORY

The first three items listed in the introduction were covered by the selection of an ascending trajectory as shown in figure 1. This curve is a plot of space position radar data obtained during the flight. The reentry corridor was essentially flown in reverse. A peak velocity of 17.8K feet per second was reached at approximately 174K feet altitude.

FLIGHT-TEST VEHICLE SYSTEM

The vehicle used to obtain the desired trajectory was designed by the Langley Research Center and is shown in figure 2. It was a four-stage solid-fuel propulsion system. It consisted of a Castor first stage with two Recruit assists, a Scat second stage, a Scat third stage, and a Recruit plus payload fourth stage (the test vehicle).

The test vehicle, or fourth stage, is shown in more detail in figure 3. It is a simple geometric shape which facilitates theoretical calculations. It is a slender probe with a 1-inch radius tip to permit some attenuation but not total blackout. It is all-metallic with a

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copper heatsink nose tip to avoid flow contamination with ablation products. The cone half-angle is 9° , the cylinder diameter is 9 inches, and the overall length is approximately 12 feet.

INSTRUMENTATION AND MEASUREMENTS

Two VHF antennas were used in the experiment. These were located as shown in figure 3. The forward slot antenna was centered approximately 1 foot from the nose tip on the conical section and was used with a 244.3-mc cw radio beacon. The aft split-body or ring antenna was located approximately 3 feet from the nose tip on the cylindrical section and was used with the 240.2-mc telemeter. The horizontal and vertical antenna patterns for the slot are shown in figure 4. The antenna patterns for the ring are shown in figure 5.

Both the cw beacon and the telemeter transmitter were of the same design and each had a nominal power output of 2 watts.

An FM/AM telemeter was used and the measurements telemetered are listed in figure 6. These are vehicle flow angle; normal, longitudinal, and transverse accelerations; nose-cone temperatures; beacon forward power; beacon reflected power; and forward slot antenna impedance. The first three measurements were made to verify proper vehicle performance and the last three items plus ground signal strength were the primary measurements of the experiment.

The forward and reflected powers and antenna impedance were measured on the transmission line feeding the forward antenna as shown in

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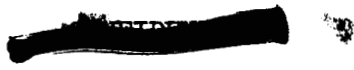


figure 7. The sensor used to measure the forward and reflected powers was a bi-directional coupler with 40-decibel directivity. The sensor used to measure impedance utilized the well-known slotted-line principle and was actually a section of the transmission line. It contained nine detectors spaced equal distances apart and at known distances from the antenna. It was rigidly constructed, made slightly over a half-wave in length, and formed into a ring to conform to space requirements.

The forward and reflected powers and the impedance measurements were made by sampling the detectors and calibration voltages with a commutating switch and telemetering the information to ground receivers on a single telemeter channel. The switch sampling rate was five revolutions per second. The directional coupler is shown in figure 8. The impedance sensor is shown in figure 9. A typical record of one commutating switch revolution is shown in figure 10.

GROUND RANGE

The ground range used for the flight was as shown in figure 11. The telemeter was recorded on magnetic tape at the Wallops Station and aboard ship. Signal strengths of both VHF signals were recorded on magnetic tape at Wallops Station, Langley Station, Coquina Beach on the North Carolina coast, and aboard ship. The look angles from the ground receiver sites with respect to the vehicle longitudinal axis were approximately 3° from Wallops, 30° from Langley, 70° from Coquina, and 90° from the ship. The signal strength measurements were accomplished



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by recording calibrated automatic gain control voltages from the receivers. Helical receiving antennas were used throughout the ground range. Before launch time antennas were pointed toward the center of the prime data period and receivers were accurately set on frequency. Operators of the ground stations were not permitted to track the antennas nor tune the receivers during the data period. This was to prevent the presence of artificial variations in the signal strength records.

TEST RESULTS

Vehicle performance was normal throughout the experiment. The planned altitude-velocity trajectory was flown, accelerations were as expected, temperatures were not excessive, and vehicle flow angle did not exceed $\pm 5^\circ$ during the data period.

Figure 12 shows trajectory information during the prime data period. Time is from 55 seconds just prior to ignition of the fourth stage to 70 seconds, altitude is from 140K feet to 320K feet, and velocity is from 11K feet per second to 17.8K feet per second dropping slightly as the vehicle coasted to higher altitudes.

Some of the flight results during the prime data period are given in figure 13. These are curves of signal strength from the forward antenna at the various ground range locations. The range stations are, from top to bottom, Wallops, Langley, Coquina, and ship with approximately 3° , 30° , 70° , and 90° look angles, respectively. The abscissa is time after launch and the ordinate is relative signal strength in

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decibels. The vertical dashed lines mark important events of the flight. Reading left to right these are (1) ignition and the start of the data period at 150K feet altitude and 11K-feet-per-second velocity, (2) fourth-stage burnout at 170K feet altitude, 17.8K-feet-per-second peak velocity, and maximum signal attenuation at all ground stations of 22 decibels to 25 decibels, (3) the end of signal attenuation at 210K feet altitude and 17.8K-feet-per-second velocity, and (4) the end of the prime data period at 320K feet altitude and 17.6K-feet-per-second velocity. The peak attenuations and the curve shapes are very similar at all receiving stations during the period of plasma sheath interference. This indicates that any antenna pattern shape changes were small. It also leads one to consider the possibility of antenna breakdown. It is believed that antenna breakdown did not occur for several reasons. First, it is difficult to break down a one-half-inch wide slot with a 2-watt transmitter and, second, the onset and decay of signal loss did not feature the abruptness usually observed when antennas break down.

Additional flight results are shown in figure 14. These are curves of signal strength from the ring antenna at the various ground range receiving stations. Again the abscissa is time, the ordinate is relative signal strength, and the vertical lines mark the same important events so marked on the previous figure. The curves, from top to bottom, are Wallops, Langley, and Coquina. The ship record of this signal was not usable because of inadequate calibrations. The signal attenuation during the plasma interference period was small for all stations being no greater than 6 decibels.

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The remainder of the flight results are shown in figure 15. The abscissa and important events as marked by the vertical lines are the same as shown on the previous figure. The ordinates, from top to bottom, are reflection coefficient angle in degrees, voltage standing wave ratio, and relative signal strength in decibels at Wallops from the slot antenna. The voltage standing wave ratio, which reached a maximum of eight, was calculated from the forward and reflected powers measured by the bi-directional coupler. The reflection coefficient angle curve is a plot of the standing wave minimum position along the transmission line as measured with the impedance sensor. Note the time correlation of high-voltage standing wave ratio and high-reflection coefficient angle with the large drop in signal strength during the plasma sheath interference period.

Look now at the right side of the figure. There is a rather large drop in signal strength in the 300K feet altitude region without a corresponding increase in VSWR and reflection coefficient angle. This drop occurred primarily at Wallops and it occurred there in the signals from both antennas. The cause of this drop is presently under investigation. Antenna pattern lobing has not been ruled out but residual ionization in the wake is a possible cause.

Antenna impedance was calculated for the plasma interference period. This was done using the amplitude of the voltage standing wave, the location of the voltage standing wave minimum with respect to the antenna, and a Smith chart. The results are tabulated in figure 16. The columns,

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from left to right, are time, altitude, velocity, VSWR, and impedance. The impedance levels are considered to be only approximate; however, the accuracy of the measurements was such that there is no doubt that the antenna mismatch was in the inductive direction.

COMPARISON OF FLIGHT RESULTS WITH THEORETICAL PREDICTIONS

Figure 17 is a comparison of theoretical signal attenuation predictions with flight results. The abscissa is inches along the axis from the vehicle nose tip and the ordinate is relative signal strength in decibels. The figure is prepared for the flight trajectory point of maximum signal loss. The bottom curve is theoretical predictions of total signal loss assuming equilibrium flow field chemistry. The top curve is theoretical predictions assuming frozen chemistry following the shock, that is, no recombination of atoms or ions. The total signal loss results measured in flight are indicated by symbols in between the two prediction curves. These measurements include loss due to antenna detuning as well as loss due to the plasma sheath. Antenna detuning was not a major factor however because the VSWR measured indicates the loss from this cause to be a maximum of 4 decibels. For the forward antenna the measured results were approximately 25 decibels signal loss. The predicted values for this antenna location were 0.35 decibel assuming equilibrium flow and 34.5 decibels assuming frozen flow. For the aft antenna the flight results were 6 decibels loss compared with predicted values of less than 0.1 decibel assuming equilibrium flow and

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29.5 decibels assuming frozen flow. The flight measurements are closer to equilibrium predictions for the aft antenna and closer to frozen flow predictions for the forward antenna. This indicates that the real conditions of nonequilibrium are somewhere in between the equilibrium and frozen chemistry. Therefore, it is apparent that a more refined understanding of the flow field characteristics is required. Some preliminary work has been done in this area at the Langley Research Center. This work will be discussed by Mr. Paul Huber in a paper entitled "Theoretical Shock Layer Plasma Flow Properties for the Slender Probe and Comparison With Flight Results."

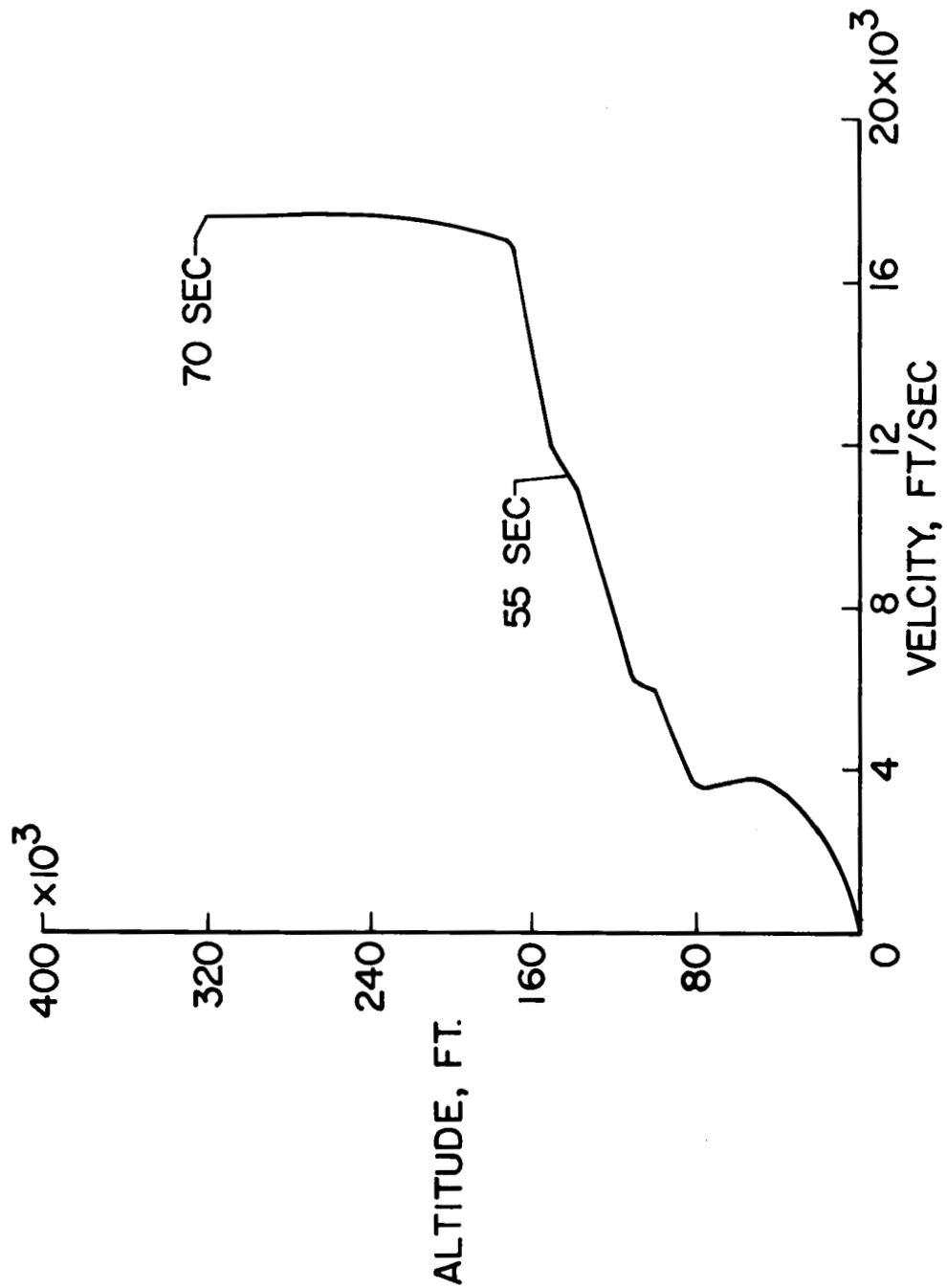
CONCLUDING REMARKS

The results of the flight covered by this paper indicate that electromagnetic and flow field prediction theories as presently applied are adequate for ball park predictions for the particular body shape and altitude-velocity trajectory flown. For more accurate predictions the nonequilibrium aspects of the flow field phenomena must be considered. The results emphasize the fact that aerodynamic shaping is a powerful method of reducing the ionization levels and minimizing the plasma sheath interference with transmission of telemetry data. The results also demonstrate that, for the antenna used, signal loss due to plasma detuning of the antenna was not excessive and the impedance shift caused by the plasma sheath was in the inductive direction.

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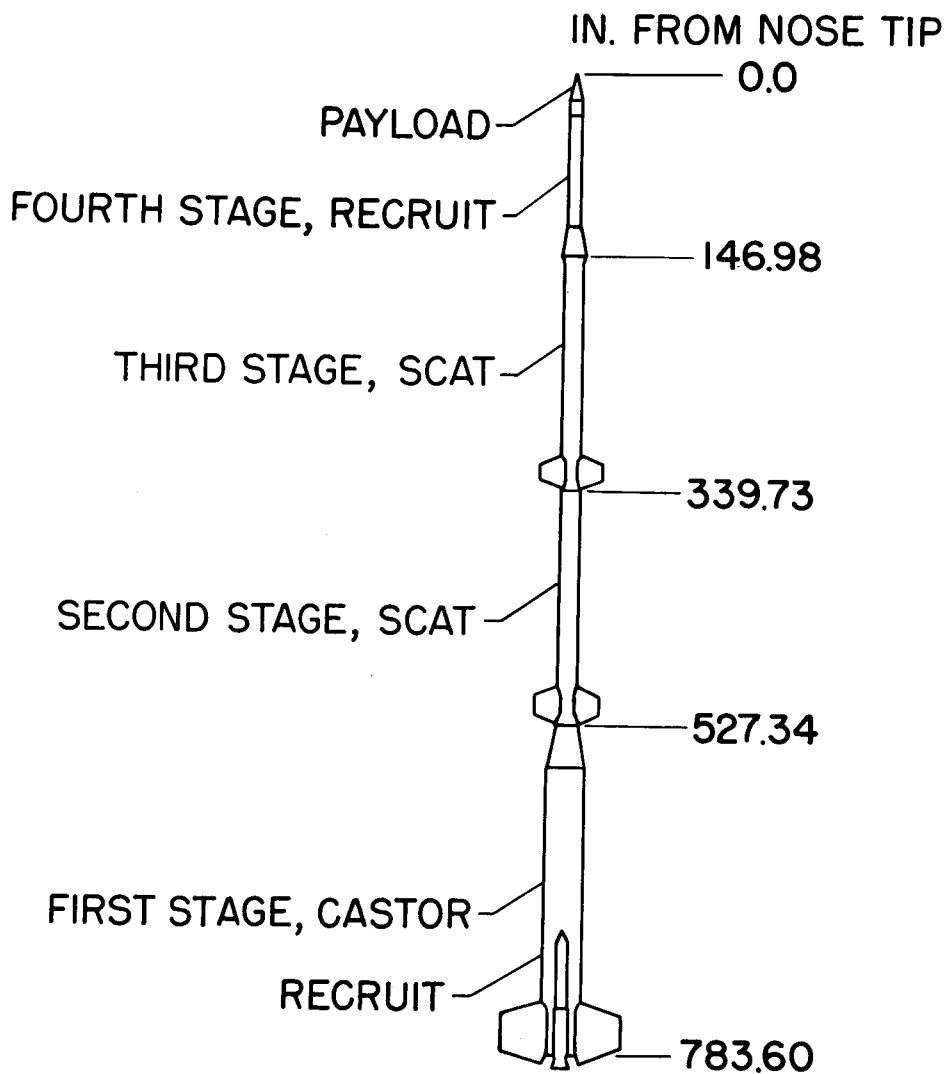
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1. Graves, George B., Jr., and Markley, Thomas J.: Telemeter Transmission at 219.5 Megacycles from Two Rocket-Powered Models at Mach Numbers up to 15.7. NASA RM L58D18A, July 1958.
2. Ellis, Macon C., Jr., and Huber, Paul W.: Radio Transmission Through the Plasma Sheath Around A Lifting Reentry Vehicle. NASA TN D-507, Jan. 1961.



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Figure 1.- Altitude-velocity trajectory.



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Figure 2.- NASA four-stage vehicle system.

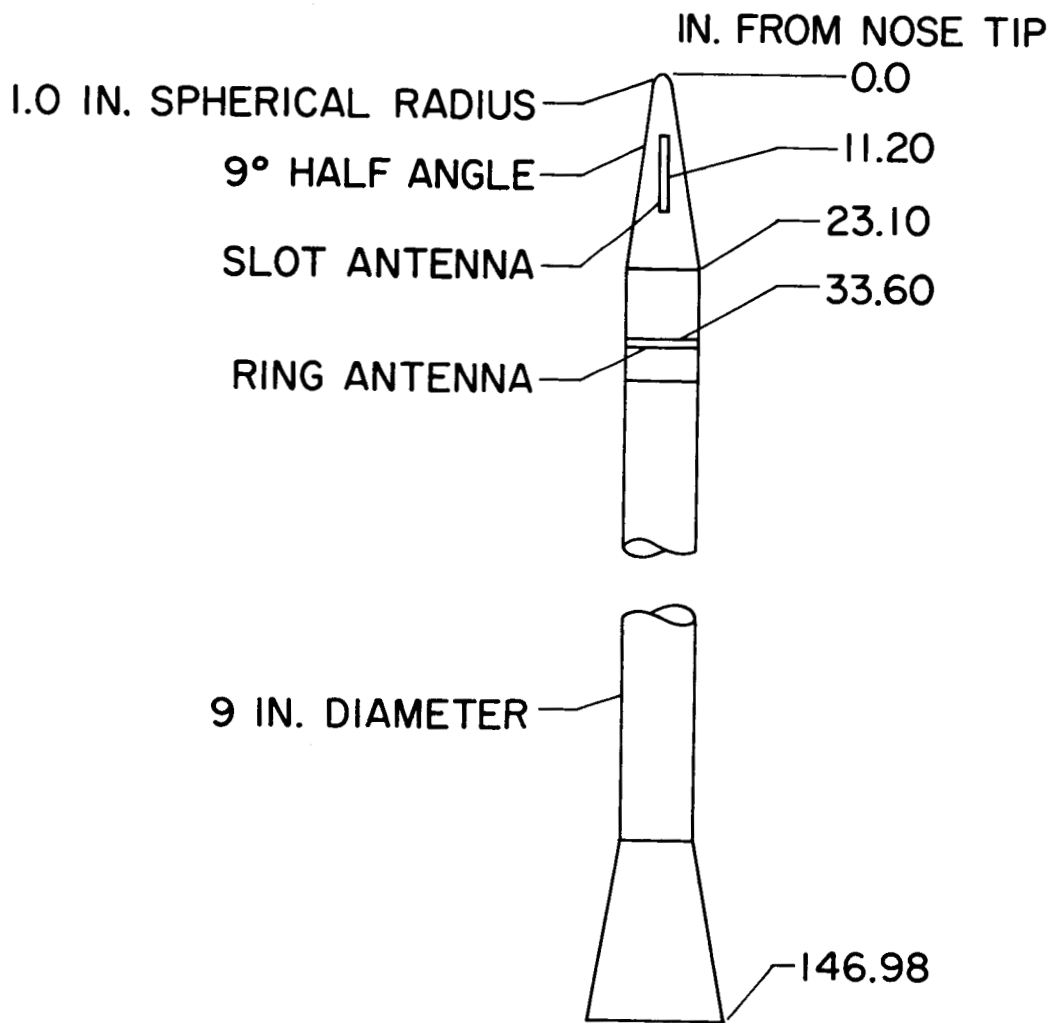
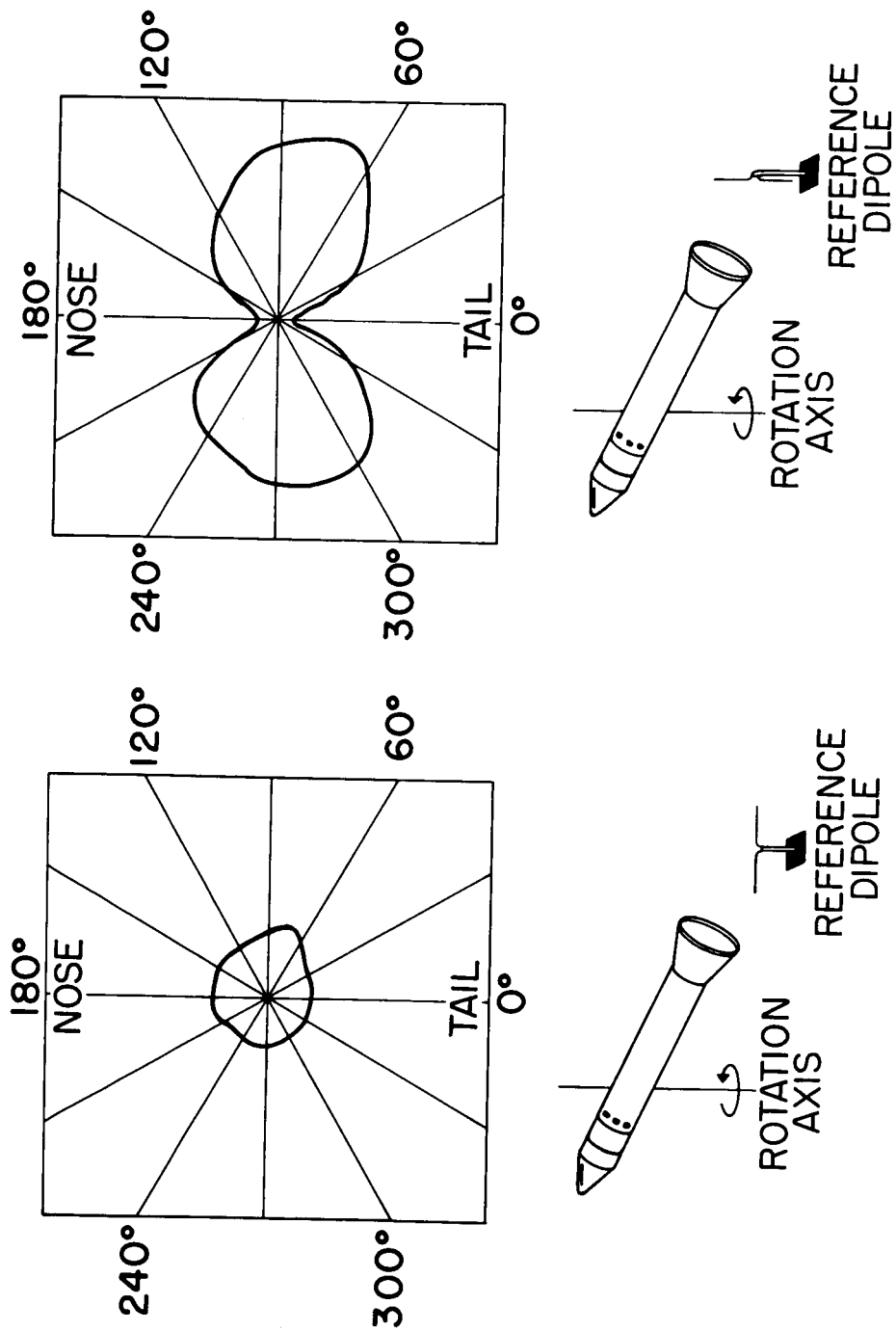


Figure 3.- Test vehicle.

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Figure 4.- Slot antenna pattern.

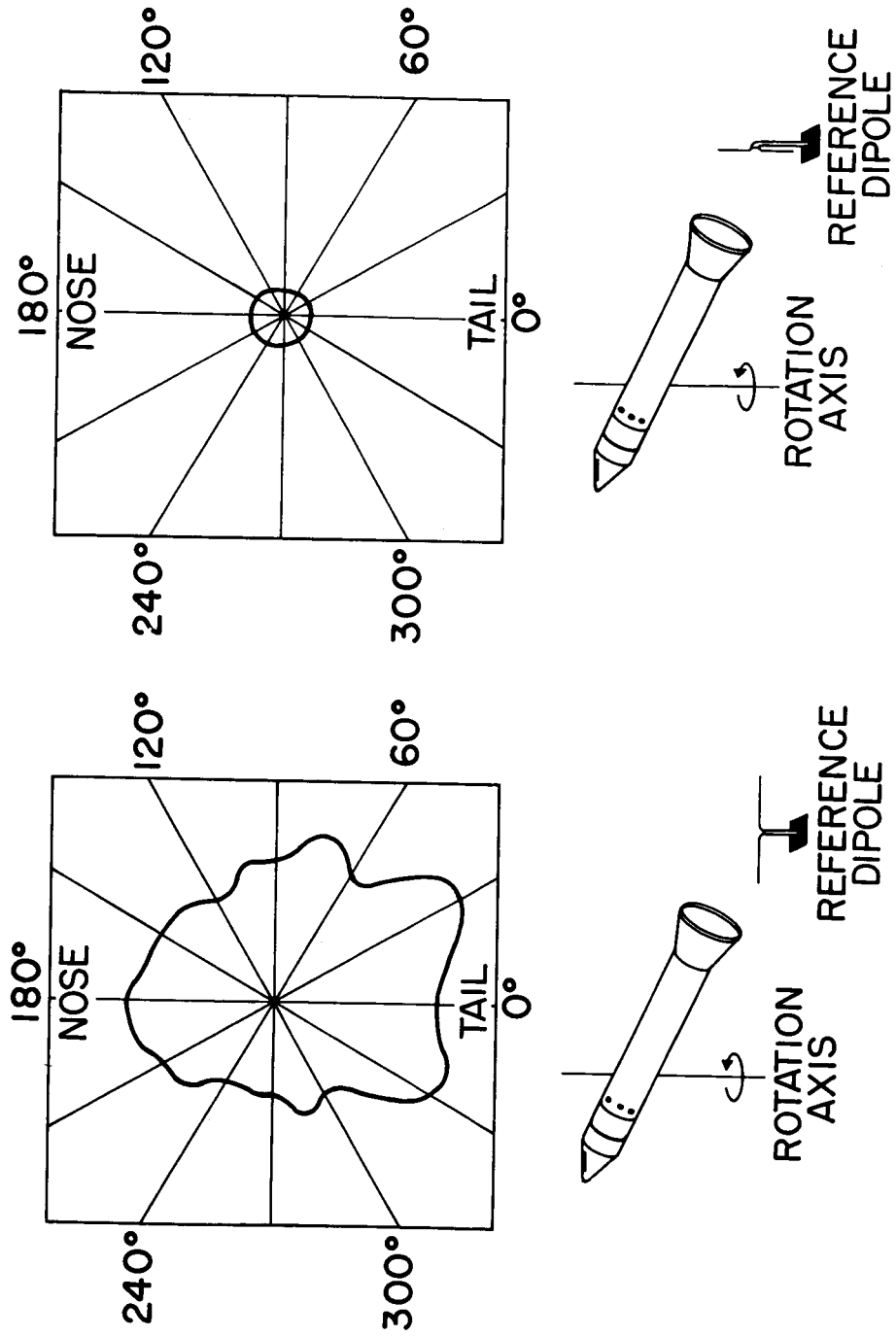


Figure 5.- Ring antenna pattern.



1. VEHICLE FLOW ANGLE

2. NORMAL, LONGITUDINAL, AND TRANSVERSE ACCELERATIONS

3. NOSE CONE TEMPERATURES

4. BEACON FORWARD POWER

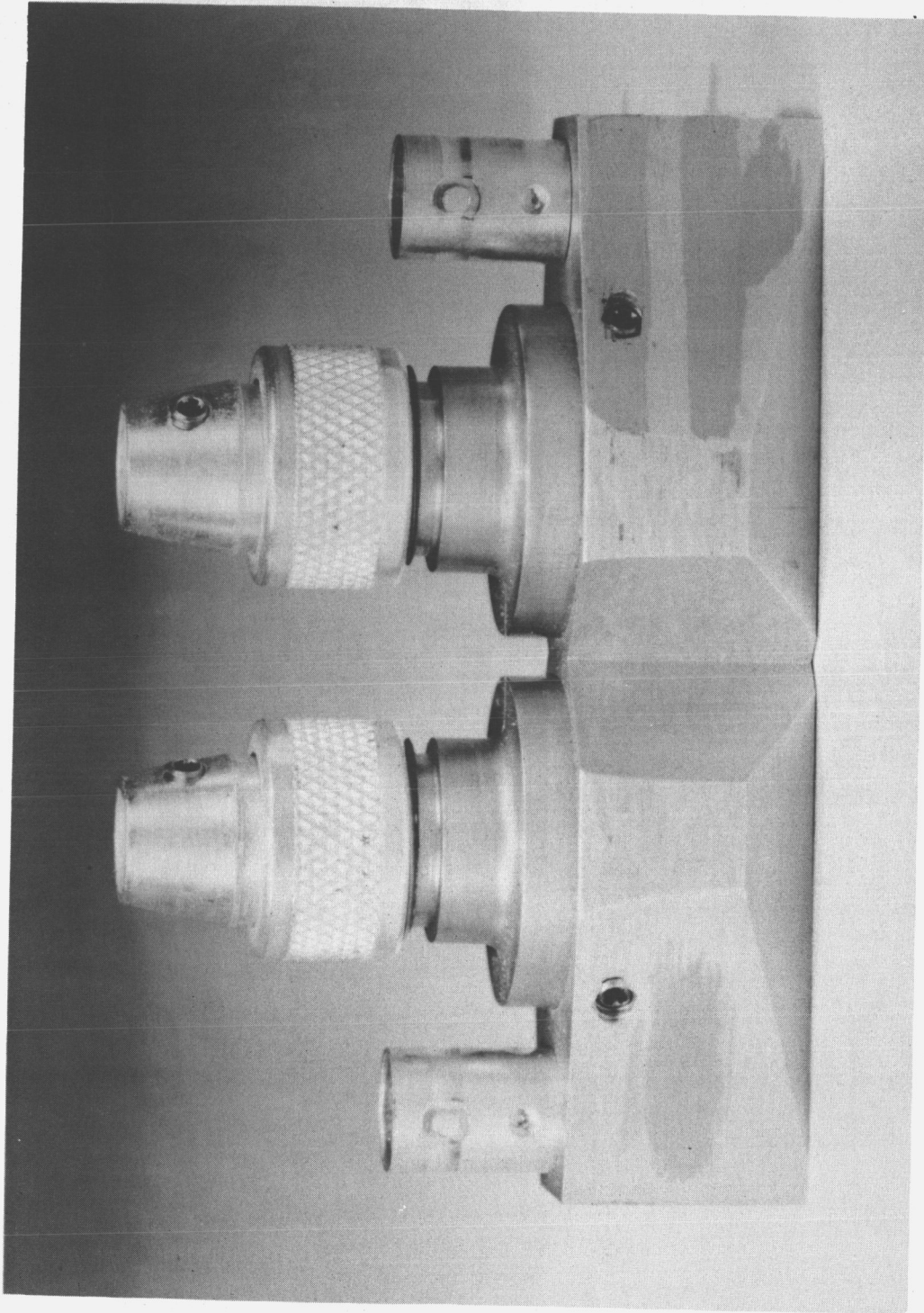
5. BEACON REFLECTED POWER

6. SLOT ANTENNA IMPEDANCE

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Figure 6.- List of onboard measurements.

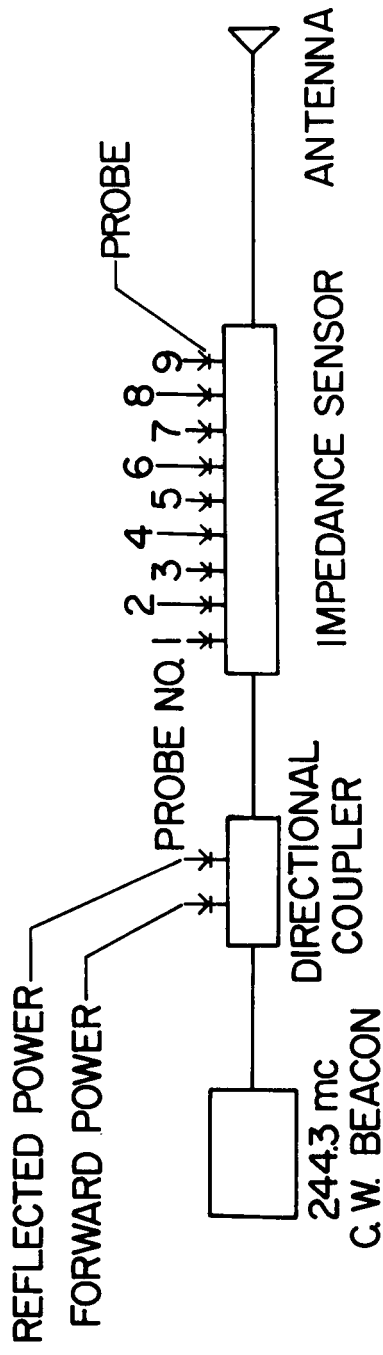
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Figure 8.- Directional coupler.

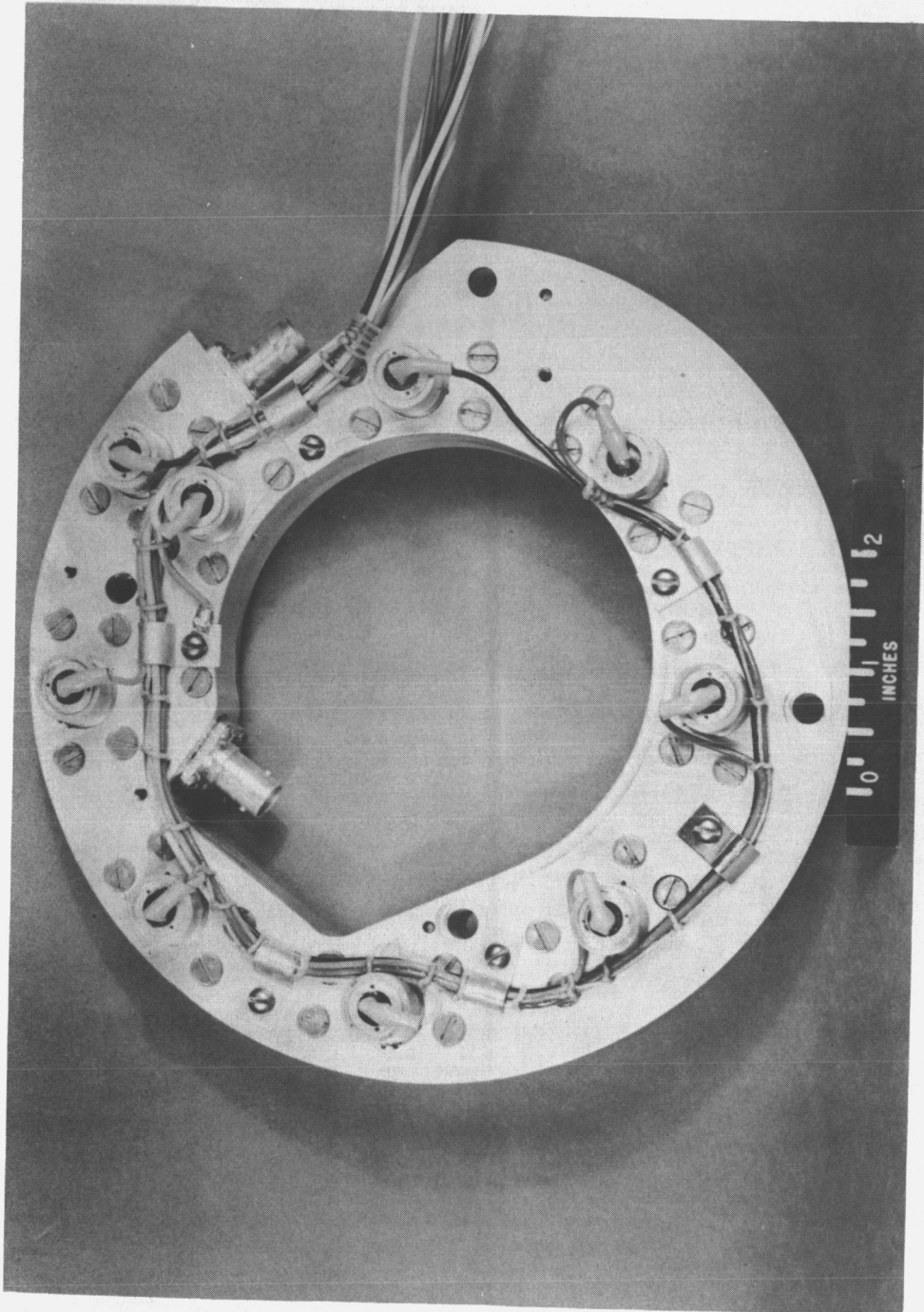
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Figure 7.- Transmission line sensors.

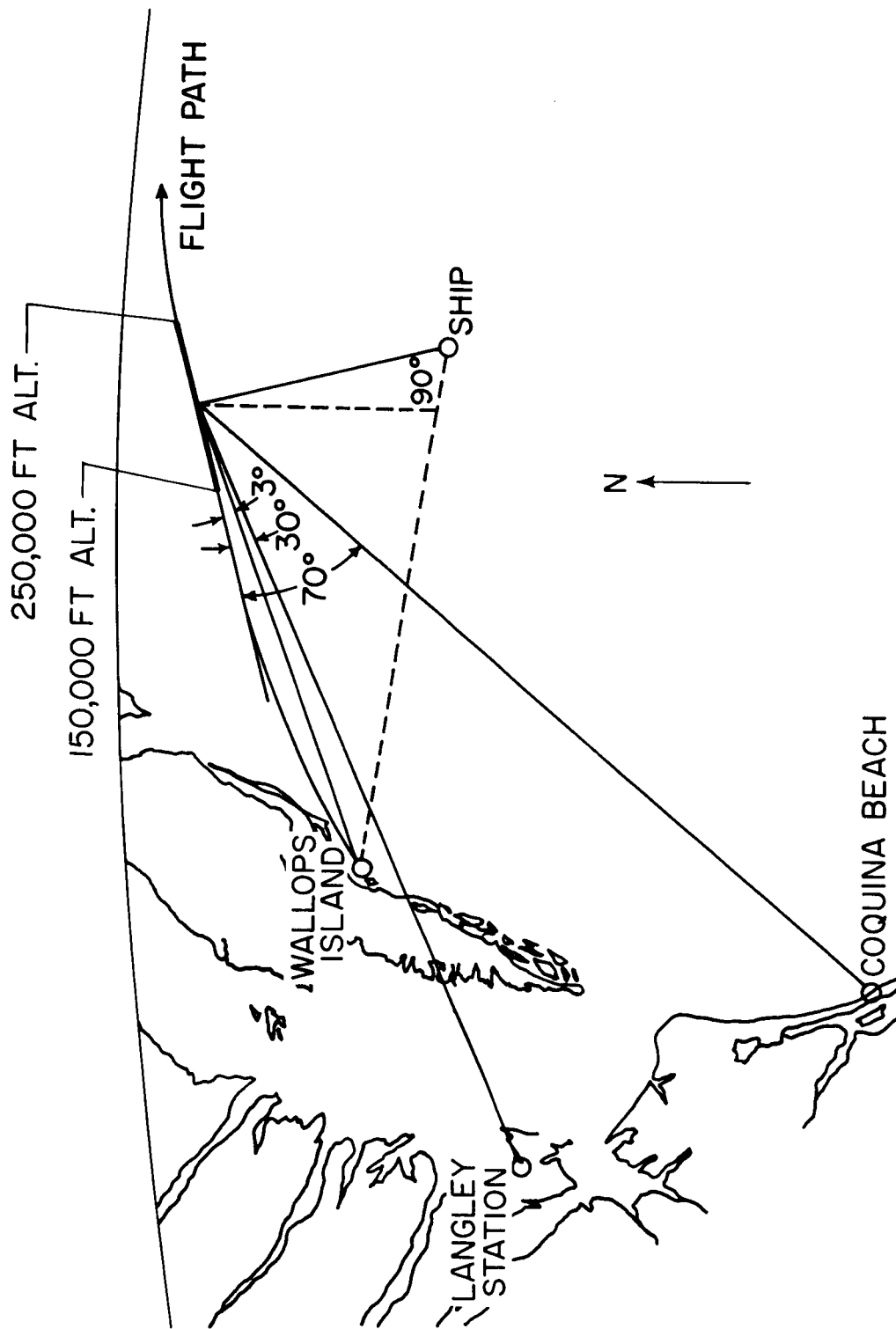
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Figure 9.- Impedance sensor.

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Figure 11.- Ground range.

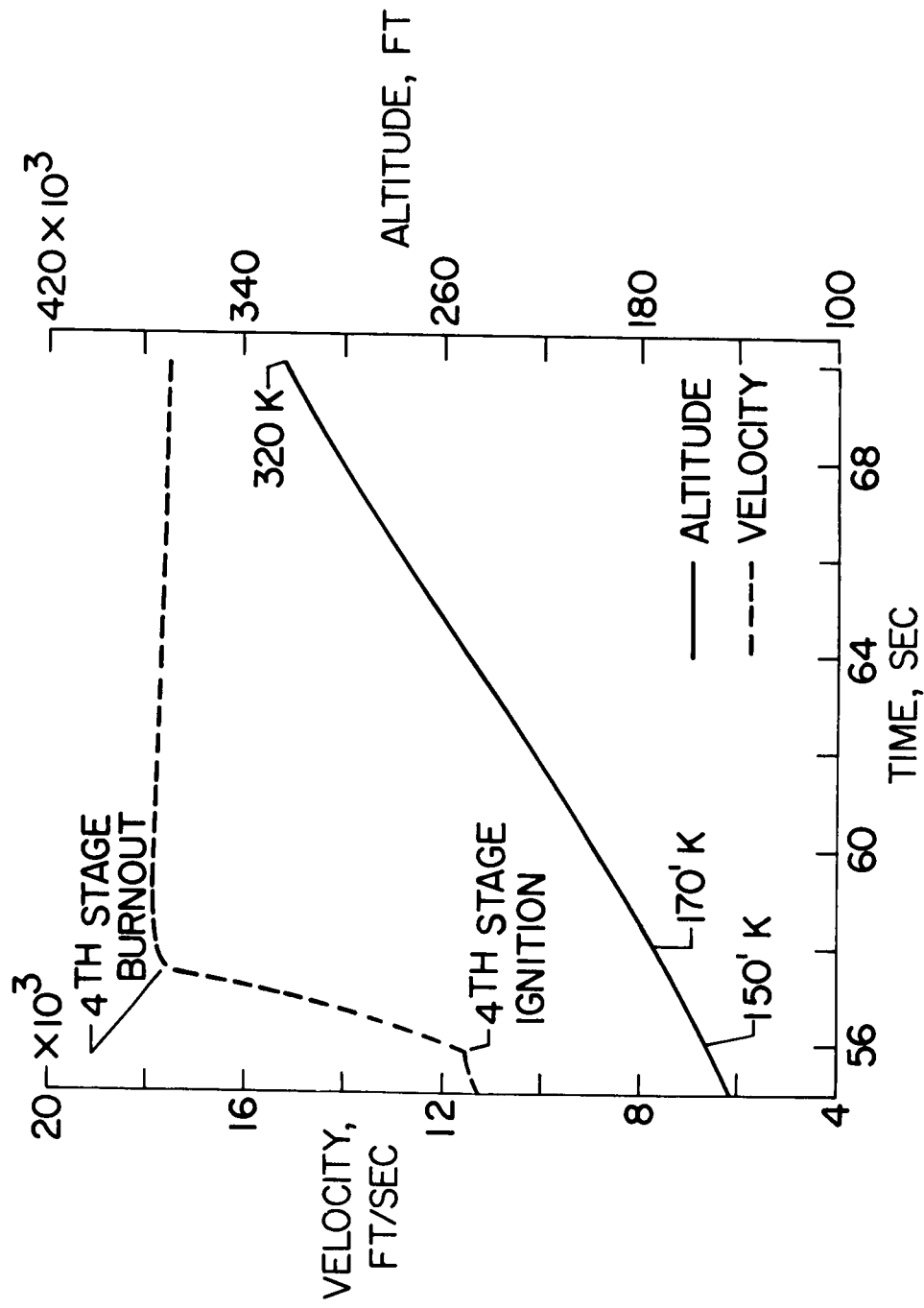


Figure 12.- Velocity and altitude during data period.

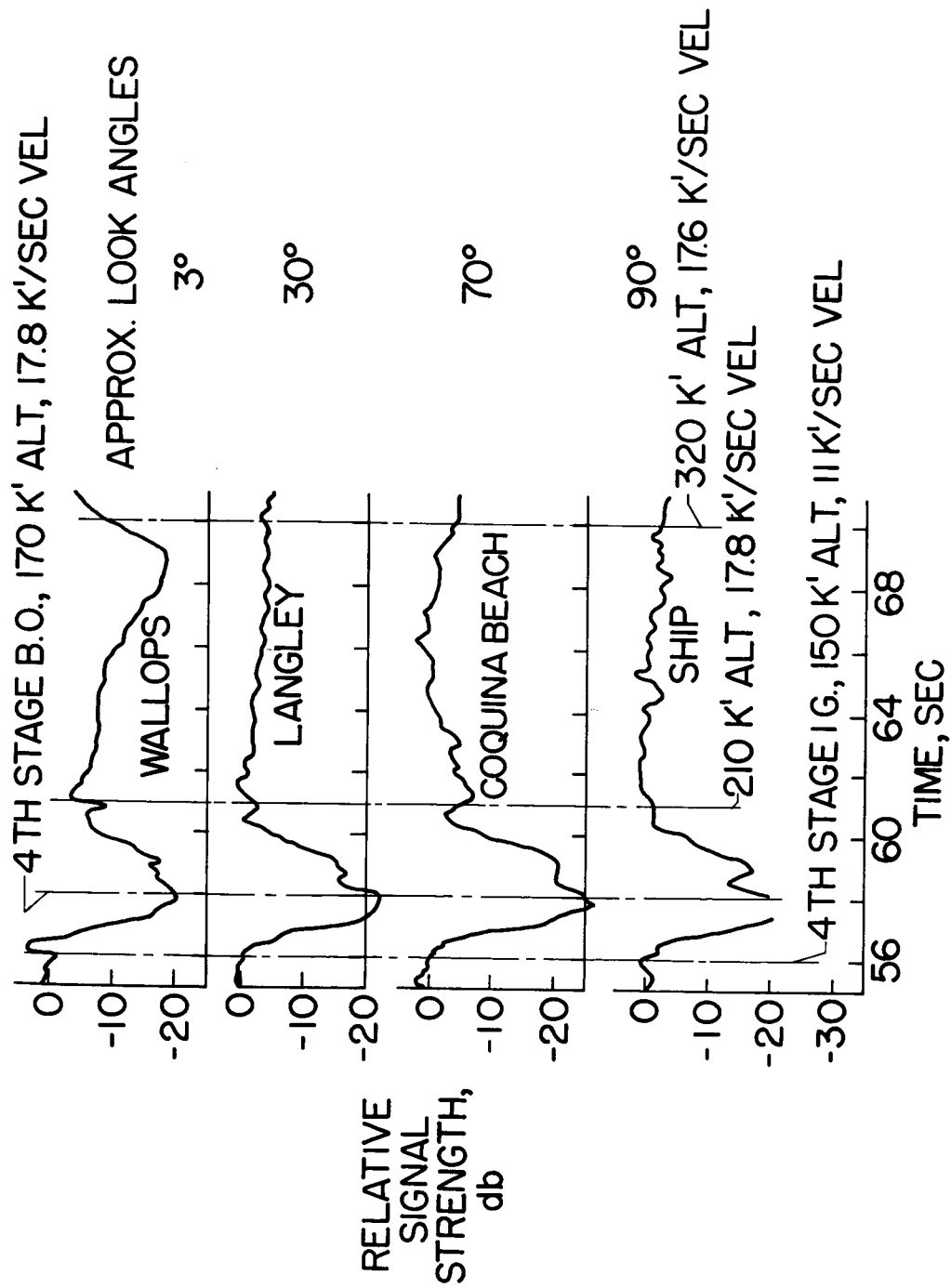


Figure 13.- Signal strength from forward antenna.

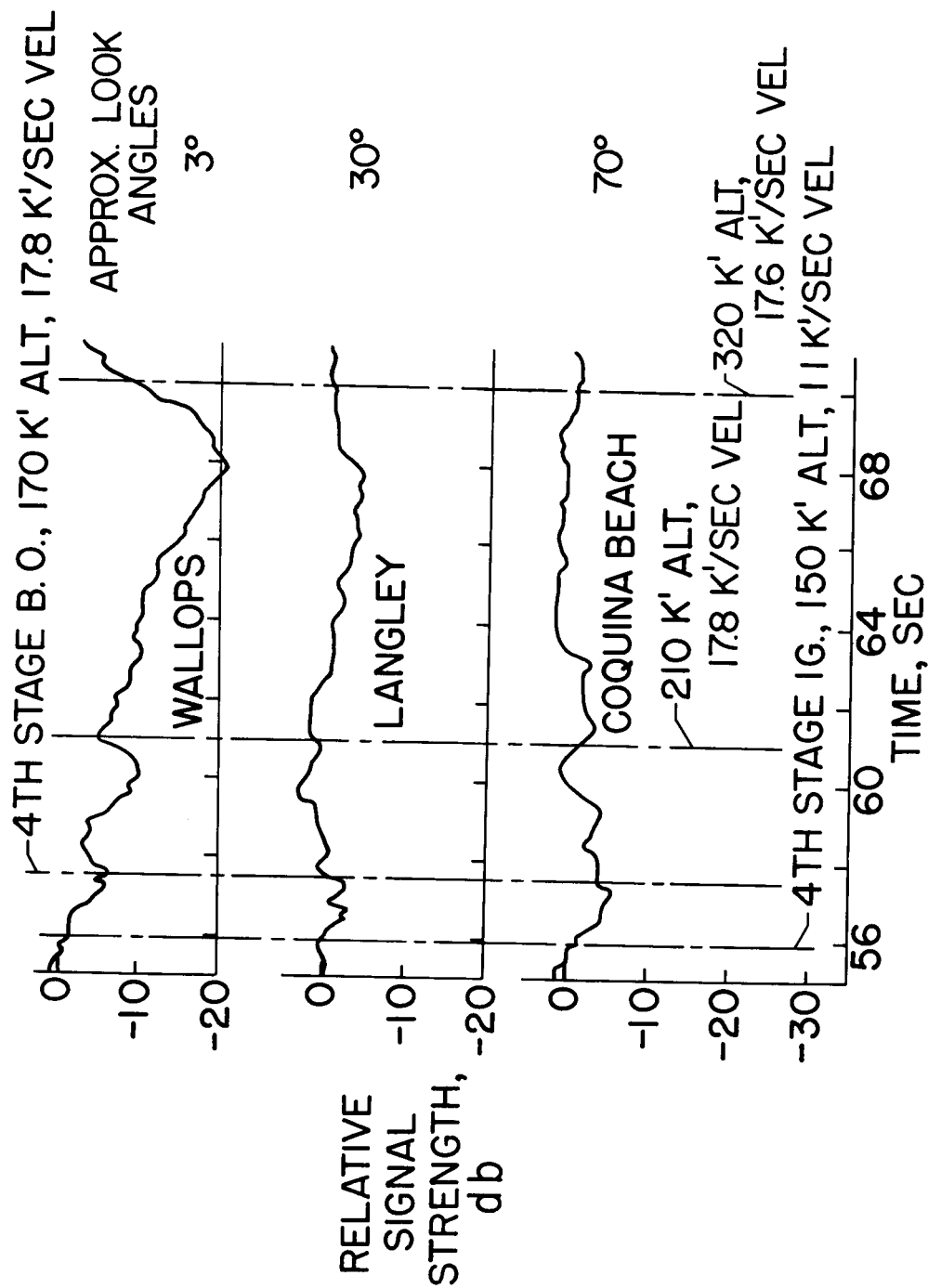


Figure 14.- Signal strength from aft antenna.

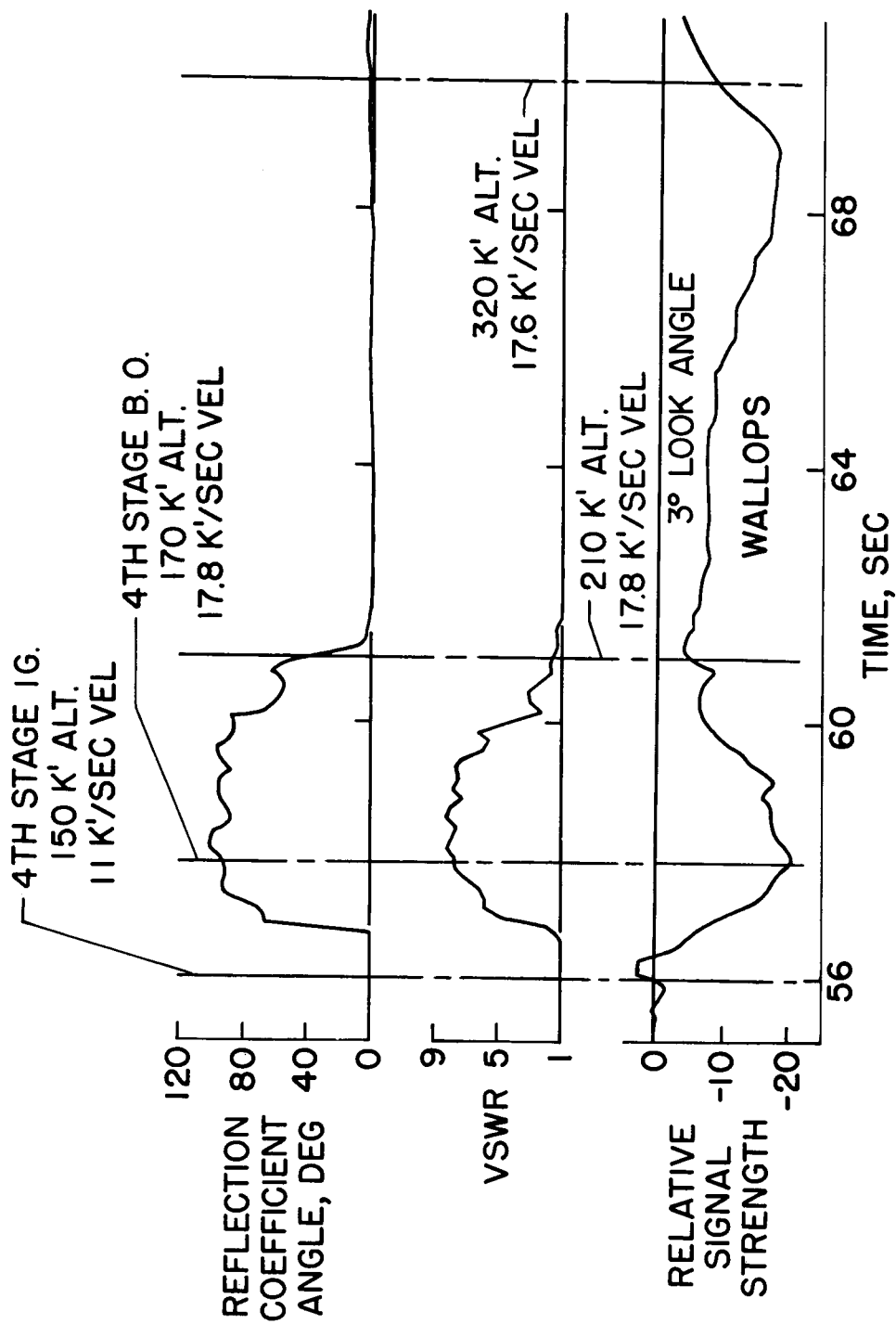
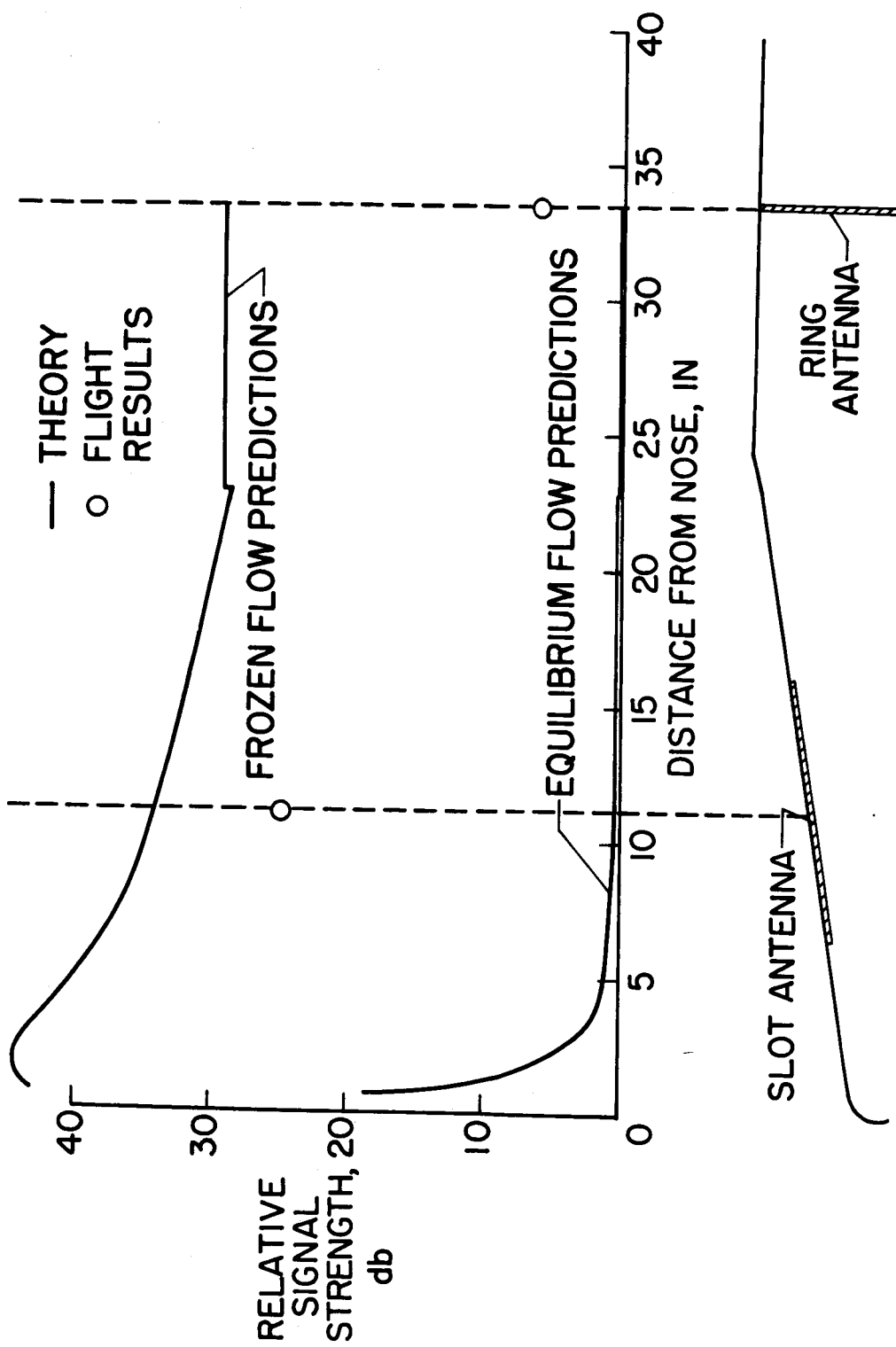


Figure 15.- Reflection coefficient angle, VSWR, signal strength.

<u>TIME</u>	<u>ALTITUDE</u>	<u>VELOCITY</u>	<u>VSWR</u>	<u>IMPEDANCE</u>
57.0 SEC	160 K'	14.5 K'/SEC	4.5	62[65° OHMS
57.5 SEC	165 K'	16.1 K'/SEC	6.0	49.2[71° OHMS
58.0 SEC	170 K'	17.8 K'/SEC	8.1	43[74.8° OHMS
59.0 SEC	183 K'	17.8 K'/SEC	7.8	47.7[75.4° OHMS
59.5 SEC	191 K'	17.7 K'/SEC	5.9	45.2[70.6° OHMS
60.0 SEC	195 K'	17.6 K'/SEC	4.5	57[64.5° OHMS
60.5 SEC	205 K'	17.6 K'/SEC	3.1	52.8[53.4° OHMS

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Figure 16.- Summary of Smith chart antenna impedance calculations.



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Figure 17.- Theoretical predictions and flight results.